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Abstract

The question of whether pupil diameter indicates information processing load during reading was investigated in three experiments involving 24 college students reading passages of varying difficulty. A TV camera and monitor, together with a video-recorder, were used to measure the diameter of the pupil under a reading condition and under three control conditions. No evidence was obtained which would suggest that the pupil dilates while reading. The generality of these results was investigated by measuring the pupil size of 20 college students while listening to tape recordings of the reading passages. No evidence was obtained which suggested that the pupil dilates while listening. These results suggested that pupil size cannot be used as an objective indication of whether or not an individual is, in fact, processing the information contained in connected discourse while he is supposedly engaged in reading or listening activities. Tables and references are included. (BT/author)

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ABSTRACT

Pupil diameter has been advanced as an index of information processing load. The question of whether pupil diameter indicates information processing load during reading was investigated in three experiments involving 24 college students reading passages of varying difficulty. A TV camera and monitor, together with a video-recorder, were used to measure the diameter of the pupil under a reading condition and three control conditions. No evidence was obtained which would suggest that the pupil dilates while reading. The generality of these results was investigated by measuring the pupil size of 20 college students while listening to tape-recordings of the reading passages. No evidence was obtained which suggested that the pupil dilates while listening. These results suggest that pupil size cannot be used as an objective indication of whether or not an individual is, in fact, processing the information contained in connected discourse while he is supposedly engaged in reading or listening activities.

INTRODUCTION

Recent research has suggested that pupil diameter indicates the degree of mental effort or mental activity involved in such tasks as problem solving (Hess & Polt, 1964), word imagery (Pavio & Simpson, 1966), short-term memory (Kahneman & Beatty, 1966), and tone discrimination (Kahneman & Beatty, 1967). Beatty and Kahneman (1966) further contend that the pupil diameter is a valid measure of the momentary state of mental effort. Stated differently, Kahneman and Beatty (1967) have referred to the validity of the pupillary measure as an index of information processing load. They explain this concept by reference to an analogy with the aggregate demand for power (total amperage) in an electrical system.

The process of acquiring information during the reading of or listening to connected discourse is a state in which one would expect that mental effort or processing load would be greater than during a control state. Therefore, it appeared fruitful to investigate pupil dilation as an indicator of the moment to moment degree to which an individual is processing information while reading or listening to connected discourse.

Payne, Parry, and Harasymiw (1968) studied pupil dilation as a measure of the difficulty of multiple-choice test questions. They state that pupil dilation is a sensitive and apparently reliable indicator of internal information processing and warrants further study. However, they interpreted their results as suggesting that pupillary dilation is not as good an indicator of item difficulty as the time taken to complete the item. These results suggest that the difficulty of the reading or listening task may also affect the pupillary dilation. However, it was hypothesized that the difficulty of the task would be reflected in a larger amount of time spent on the more difficult materials while the pupil dilation remained at a constant high level reflecting a high degree of information processing load during reading of all levels of difficulty.

In general, the purpose of the following research was to investigate pupil dilation during the processing and storage of the information contained in connected discourse. At the outset, the effect of reading upon pupillary dilation was investigated in a series of experiments and then the mode was shifted to listening for the final experiment.

STUDY 1

Introduction

The major purpose of the experiment was to determine the effect of reading upon pupil dilation. A minor purpose was to investigate the effect of the difficulty of the reading material upon pupil dilation. Since dilation is always in relation to a control condition, the selection of an appropriate control was critical. Three control conditions were used: fixation upon a point approximately 11 inches away, fixation upon each of a series of numbers and fixation upon each of the words in a reading passage which had been turned upside down.

Method

Subjects. Eight college student volunteers were paid for their one hour of participation in the experiment.

Equipment. The pupil was video-taped using a system which included a Panasonic TV Camera, Model WV-220P; an adjustable extension tube on a Makro-kilar lens (1 : 2. 8/90) manufactured by Heinz Kilfitt Muchen; a 1" video recorder, Panasonic Video Master, 2100 SD; two adjustable desk lamps (2-15 watt fluorescent tubes in each lamp); a head positioning apparatus, which provided a stationary forehead rest and an adjustable chin rest; and a clamp device for holding the stimulus cards.

The TV camera was mounted on a 22-1/2" x 36" horizontal surface, 37" above floor level. The camera was mounted so that its horizontal position was in the same horizontal plane as the eye. The eye and camera lens were approximately 13" above the mounting surface. A schematic plan drawing of the relative position of the subject, camera, and lights is presented in Fig. 1 on the following page.

Materials. The stimulus materials were 5 x 8 white index cards which had been cut to 5 x 5. The number card was a stimulus card with the numbers one through nine typed on the card. The "1" was on the top left part of the card, the "2", top middle, the "3", top right, the "4", middle left, and so on. The numbers thus provided fixation points on the card for eight border positions and one center position.

There were eight different reading cards, each containing one 150-word reading passage. The passages were selected from the set of 36 passages originally scaled for difficulty by Miller and Coleman (1967). They were selected to represent four levels of difficulty. Recently, Aquino (1969) has further studied the difficulty level of these passages and has published the 36 paragraphs in their entirety. Their order of presentation in Aquino's article will be used as an identification

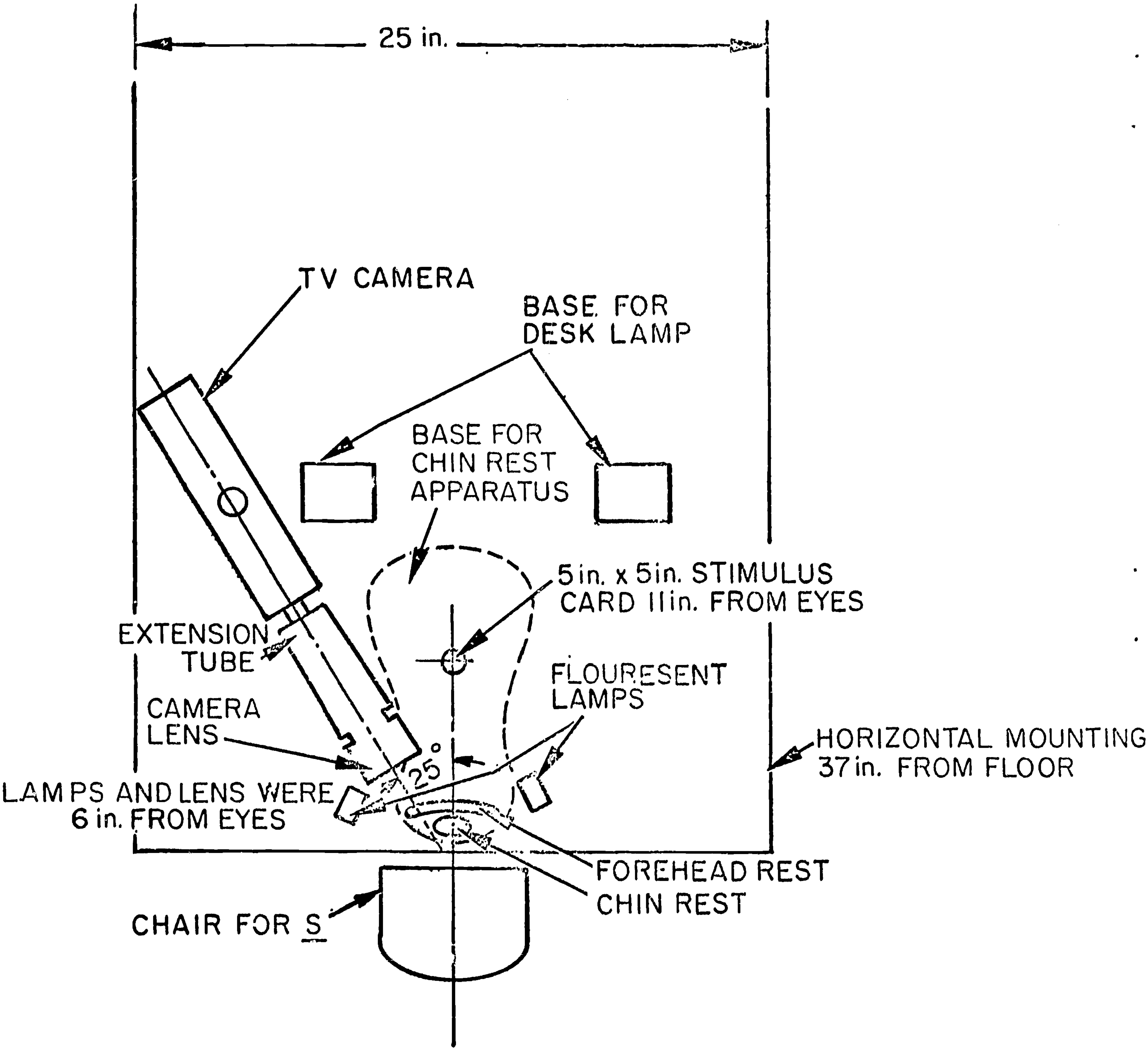

FIG. 1. PLAN VIEW SCHEMATIC OF APPARATUS FOR VIDEO-RECORDING THE EYE WHILE READING OR LOOKING AT STIMULUS CARDS

number when referring to specific passages. The eight paragraphs (two at each difficulty level) used in the study are shown below represented by their Aquino identification numbers and corresponding number and letter identification used in the present study.

Very Easy	13 (1A), 10 (1B)
Moderately Easy	22 (2A), 25 (2B)
Moderately Difficult	27 (3A), 32 (3B)
Very Difficult	33 (4A), 36 (4B)

The comprehension tests for these reading passages were cloze tests (see Taylor, 1953). Ten words were arbitrarily selected in each passage as test items and these words were deleted when the passage was retyped as a test. The items were all selected from the lexical words, i. e., nouns, adjectives, adverbs, and verbs, rather than from the function words, i. e., articles, conjunctions, prepositions, and pronouns. The items were also selected to be approximately equally spaced throughout the passage.

Instructions. The following instructions were read to S at the beginning of the experimental session: "This is an experiment to investigate the function of the eyes when reading. You will be asked to read some short paragraphs and then take a sentence completion test on the paragraphs."

Procedure. Upon entering the laboratory room, S (a) was instructed to sit in front of the experimental apparatus, (b) was given the instructions concerning the nature of the experiment, (c) was asked to place his chin in a chin rest, and (d) was asked to fixate upon the number "5" on the center of the card in front of him. If necessary, E then adjusted (a) the chin rest, (b) the height of the chair, or (c) the focus of the television camera to fit each S. E focused on S's left eye so that it was in the center of the TV monitor.

After adjustments were made, S was asked to move away from the apparatus and E gave S a verbal preview of the practice procedures to follow. S was then asked to return to the chin rest, and the focus and position of the eyewere readjusted if necessary. S was instructed to close his eyes for approximately 3 sec. E then activated a stop watch, instructed S to open his eyes, and started the video-tape simultaneously. S fixated upon the number "5" in the center of the card (Baseline Fixation Control condition, BFC).

At the end of 20 sec. S was instructed to close his eyes, and after 5 sec. was instructed to open them and look at each of the numbers one through nine on the card. S was instructed to continue looking at each of the numbers one through nine, i. e., when nine was reached, S was to return to one and start again (Eye Movement Control condition, EMC).

At the end of 20 sec., S was signaled to close his eyes. E then removed the number card from the viewing position. S was then instructed to open his eyes and begin reading immediately (READ condition).

When S finished the passage he was instructed to close his eyes. E recorded the reading time with an electric timer. With S's eyes closed, E turned the passage card upside-down and then instructed S to open his eyes and look at each word on the card as though he were reading (Upside-down Looking Control condition, ULC). That is, S was to start in the upper left corner, look at each upside-down word from left to right and continue down each line of the card until the last word was looked at in the lower right hand corner of the card. S was asked to refrain from trying to recognize the meaning of the upside-down words while he was looking at them.

S was instructed to close his eyes when he finished reading. E used a timer to record the duration of this condition. If E noticed on the TV monitor that S tended to skip over words, he was instructed to decrease his rate of looking at the upside-down words so that he was fixating upon each word. These procedures produced looking time values which were approximately equal to the corresponding reading time values.

After the ULC condition, S was asked to move away from the apparatus and take a seat at a desk where the test on the passage was administered. S was told that the passages had four levels of difficulty: very difficult, moderately difficult, moderately easy, and very easy. The S was told the difficulty level of his particular practice passage so that he would have some idea of what to expect for the experimental passages. S was given three minutes to complete the test. (Most individuals finished each test in less than two minutes.) Then, the entire procedure was reviewed and S was informed that for the experiment he would repeat the same procedural cycle for seven more passages.

Design. Table 1 contains the general design for the study. Ss were tested individually and were assigned sequentially to the four Latin-square passage orders. The first passage presented was always the practice passage and the following seven were experimental passages. However, passages 2-4 were also considered by E as practice passages to allow anxiety and the "learning to learn" effect to stabilize.

TABLE 1

Passage Presentation Order for a Set of Four Subjects

	Order							
S	1	2	3	4	5	6	7	8
1	1A	2A	3A	4A	1B	2B	3B	4B
2	4A	1A	2A	3A	4B	1B	2B	3B
3	3A	4A	1A	2A	3B	4B	1B	2B
4	2A	3A	4A	1A	2B	3B	4B	1B

Measures. Ss were scheduled at two hour intervals and the hour between Ss was used to record the data from the video tape. Three data points were sampled from each of the four conditions (BFC, EMC, READ, and ULC) for the four paragraphs (1B, 2B, 3B and 4B). Thus, a total of 48 pupil diameters were measured for each S.

The sampling procedure for each condition was as follows: BFC--Sample 1 was taken 10 sec. from the beginning of the condition, Sample 2 was taken approximately 2 sec. later, and Sample 3 was taken approximately 2 sec. after Sample 2; EMC -- Sample 1 was taken from the first fixation on the number "5" following the 10 sec. point in the condition interval, i. e., S completed a cycle of looking at 6, 7, 8, 9, 1, 2, 3, and 4 before the next sample was taken; Sample 2 was taken from the next fixation on the number "5" and Sample 3 was taken from the following fixation on number "5" after Sample 2; READ--Sample 1 was taken from the first fixation in the center of the monitor screen following the 10 sec. point in the condition interval, Sample 2 was taken when S had finished the line he was reading f or Sample 1 and had again reached the center of the screen while reading the following line, and Sample 3 was like Sample 2 except the measurement was taken from the following line; ULC--Samples 1-3 were taken in a manner exactly like those in the READ condition.

The pupil diameter was measured directly from the stop-action image on the monitor screen. The measurement was accomplished by affixing a transparent grid (10 squares per inch) to the monitor screen. The horizontal coordinate which was tangent to the upper edge of the pupil was observed and recorded by E and likewise the horizontal coordinate which was tangent to the lower edge of the pupil was also observed and recorded by E. Thus, the pupil diameter was always the vertical diameter and this value was calculated by subtracting the value recorded for the lower edge from the upper edge.

If any planned measurement coincided with or immediately followed an eye blink the video tape was reversed and the measurement was taken immediately preceding the eye blink to eliminate the unwanted dilation immediately following the eye blink. Also, all measurements were taken during fixations since the image was blurred during eye movements.

All pupil diameters were, therefore, recorded in inches as they appeared on the monitor. These diameters varied between individuals from approximately 2.5" to 5.0". The actual size of the pupil in millimeters was not estimated since the distance between the eye and the camera varied with the contour of the S's head; the focus, therefore, varied slightly between individuals. However, by focusing upon circles of known diameter placed in a normal position of the eye, the magnification of the system was estimated. A diameter change of 0.1 inches on the monitor screen was thus estimated to equal 0.00565 inches, or 0.14 mm, on the actual eye. The magnification on the monitor was, therefore, approximately 18 times the actual size of the pupil. It was impossible to estimate the horizontal tangent to the pupil closer than the nearest 0.1 inch and therefore this was the precision of the measurements, 0.1 inch on the monitor or 0.14 mm of pupil diameter.

After each of the three samples had been taken for each passage-condition, the median value was selected to represent the condition for additional data analyses, i.e., for each individual reading each passage there was one pupil diameter for each of the four conditions. Since slight changes in the head position or movement in the apparatus often necessitated refocusing at the beginning of each passage trial, pupil diameters could not be directly compared between individuals or between passage-conditions within-individuals. In order to make these comparisons, pupil diameters under each of the three conditions -- EMC, READ, ULC -- were adjusted for baseline differences by subtracting the pupil diameter under the BFC condition.

Secondary to the pupil diameter measurements were the passage reading time data and the test scores on the passages. These data were analyzed solely to ascertain whether the difficulty of the reading passages was reflected in reading durations and comprehension scores. The times recorded for looking at the upside-down words were not analyzed. These durations were recorded only to provide additional immediate feedback to E relevant to the similarity between the eye movements under this condition and the eye movements during the reading condition.

Results and Discussion

The mean reading times for the four passages increased with the difficulty level of the passage (1B: 0.63 min. ; 2B: 0.78 min. ; 3B: 0.79 min. ; and 4B: 1.08 min.) and the mean number correct on the comprehension tests decreased with the difficulty level (1B: 9.6; 2B: 6.9; 3B: 5.4; 4B: 2.4). It therefore appeared that the difficulty variable had been manipulated.

Table 2 contains the mean pupil dilation for the four passages under the two control and one experimental conditions. There were only four mean dilations which were greater than the accuracy of the measurement, 0.10 inches, and the largest dilation was only 0.20 inches. These differences are quite small in relation to the size of the dilation, approximately 0.50 mm reported by Kahneman (1966). A 0.50 mm dilation would result in a change of approximately 0.36 inches on the TV monitor in the present study.

TABLE 2

Mean Pupil Dilation in Relation to Baseline for Three Conditions and Four Reading Passages (N=8)

	Conditions		
Passage	EMC (Control)	READ (Experimental)	ULC (Control)
1B	.04*	.05	.03
2B	.06	.14	.08
3B	.01	.11	.02
4B	.11	.20	.09
Mean	.06	.12	.05

*Mean values are in inches of dilation as measured on a TV monitor which had magnified the pupil approximately 18 times.

At this point in the data analysis, a contaminating variable was discovered. Although most of the measurements were made in the center of the screen, some were not. A correlation was discovered between the position of the pupil on the screen and the pupil size. That is, the screen was distorted so that the pupil increased slightly in diameter as it changed in position on the screen from bottom to top. During the reading of the more difficult paragraphs, the individuals had not progressed as far down the screen during the first 10 sec. of the READ condition as they had during the less difficult passages. Thus, these latter pupil dilations tended to be larger.

A correction factor was formulated by using a test circle of consistent diameter. When the correction factor was applied to the data, the differences in Table 2 became less marked. These corrected values are presented in Table 3. Notice that the largest dilation was only .17 and that there appeared to be no trend for the dilation to increase as the difficulty of the passage increased. Furthermore, the mean of the mean differences for each of the three conditions were all approximately equal. Thus, there appeared to be little evidence to suggest that the pupil dilated while the individuals were processing information during the reading of the paragraphs.

TABLE 3

Mean Pupil Dilation in Relation to Baseline for Three Conditions and Four Reading Passages After Correction for Screen Distortion (N=8)

		Conditions	
Passage	EMC (Control)	READ (Experimental)	ULC (Control)
1B	.07*	.07	.07
2B	.09	.17	.14
3B	.05	.09	.06
4B	.11	.16	.06
Mean	.10	.12	.08

*Mean values are in inches of dilation as measured on a TV monitor which had magnified the pupil approximately 18 times.

It did not appear fruitful to try to replicate the results in Study 1 under precisely the same experimental conditions. Therefore, it was decided that modifications should be made in the procedures prior to the collection of additional data.

STUDY 2

Introduction

In order to be relatively assured that the motive-incentive conditions were not a major variable affecting the pupil dilation, the instructions in the following study were modified in a manner designed to increase motivation. Furthermore, the measurement procedures were modified slightly to further control for the screen distortion.

Method

The method was exactly the same as in Study 1 except for the following three changes:

1. The instructions read to each S were changed to increase motivation by providing S with knowledge of results and by indicating that S's performance might be categorized by E as "bad." The instructions were: "This experiment is designed to investigate the function of the eyes during reading. We are interested in the differences in function between good and poor readers. You will read a number of short paragraphs and then take sentence completion tests on these paragraphs. I will not comment on how well you did each time, but I will grade each test immediately after you have finished so that you will know how many blanks you filled-in correctly."

2. E marked the incorrect responses in the presence of S immediately after he had finished each test.

3. The measurement procedures were modified so that fewer measurements were made in positions other than the exact center of the monitor screen. That is, if S moved his head slightly under condition EMC, so that his pupil was in the center of the screen when he was fixating, for example, on "6" instead of "5", then the center fixation was used instead of the "5" fixation. Also, under conditions READ and ULC, instead of always selecting the first sample at the 10 second point, the first sample was selected for a line that was approximately in the center of the screen. With these modifications it was still imperative that the correction factor, developed in Study 1, be applied in many instances since Ss often changed their head position slightly.

Results and Discussion

Mean reading times for the four passages again increased with the difficulty level of the passage (0.75, 0.83, 0.95, and 1.33 min.) and mean number correct on the comprehension tests again decreased with the difficulty level (8.8, 6.6, 4.0, and 2.2). Although the mean reading times were higher in Study 2 than Study 1, the mean comprehension scores were lower. Thus, it appears that the group in Study 2 were probably slightly less able, rather than more motivated. These data suggest that Ss were probably doing their best in both Study 1 and Study 2.

Table 4 contains the mean pupil dilations for the four passages under the two control and one experimental conditions. Notice that no mean dilation is greater than the accuracy of measurement, 0.10, and the average dilation over all four passages was equal, 0.05, for all three conditions.

TABLE 4

Mean Pupil Dilation in Relation to Baseline
for Three Conditions and Four Reading Passages (N=8)

	Conditions		
Passage	EMC (Control)	READ (Experimental)	ULC (Control)
1B	.04*	.05	.06
2B	.00	.02	.01
3B	.08	.09	.06
4B	.06	.05	.05
Mean	.05	.05	.05

*Mean values are in inches of dilation as measured on a TV monitor which magnified the pupil approximately 18 times.

These data further confirm the results of Study 1 and provide no evidence that the pupil dilates when individuals are processing the information contained in connected discourse.

It did not appear to be fruitful to replicate these results using the same procedures.

STUDY 3

Introduction

The major purpose of Study 3 was to further extend the results of Studies 1 and 2 under slightly modified procedures. In this study, Ss were not allowed to read at a rate of their own choosing but were given a short fixed amount of time to spend reading. This procedure was used to produce a consistently high level of information processing load for all levels of passage difficulty. That is, S would probably try to process as much information as he could during the time interval, thus keeping the load at a maximum during the entire 20 seconds.

Method

The method was exactly like that in Study 2 with the exception that Ss were only given 20 seconds to read each paragraph and 20 seconds to look at the upside-down words.

Results and Discussion

Mean comprehension scores again decreased with the difficulty level of the passages (7.5, 5.3, 2.6, and 1.2), and in each of the four comparisons, the scores were lower than those of Studies 1 and 2. Although it was never seriously questioned that Ss were processing information while they were looking at the words, it was possible that the items could have been answered correctly without reading. Thus, these data provide some evidence that Ss were processing information while they were fixating upon the words under the reading conditions.

Table 5 contains the mean pupil dilation in relation to baseline for the three passages under the two control and one experimental condition. Although the mean of the four mean passage dilations under the reading condition, .15, was greater than the accuracy of measurement, .10, it was essentially equal to the mean dilation for all four passages under the ULC condition, .14.

TABLE 5

Mean Pupil Dilation in Relation to Baseline
for Three Conditions and Four Reading Passages (N=8)

Conditions

	Conditions		
Passages	EMC (Control)	READ (Experimental)	ULC (Control)
1B	.08*	.21	.15
2B	.11	.22	.20
3B	-.01	.12	.12
4B	.04	.06	.10
Mean	.05	.15	.14

*Mean values are in inches of dilation as measured on a TV monitor which magnified the pupil approximately 18 times.

Therefore, the results of Studies 1-4 do not provide evidence which would suggest that the information being processed while reading is associated with a greater pupil size. It is possible that these results cannot be generalized to another mode of processing the information contained in connected discourse. Furthermore, it is possible that some other variable is associated with eye movements which contaminated the data in these studies, i. e., such as the measurement procedures. Therefore, it appeared desirable to investigate the effect of listening upon pupil dilation. Listening is another mode of processing the information contained in connected discourse. Listening has the advantage of allowing pupil dilation to be measured during the information processing activity without accompanying eye movements as in reading.

STUDY 4

Introduction

The purpose of the following study was to investigate the effect of listening upon pupil dilation to determine if the results of Studies 1, 2, and 3 could be generalized beyond the reading mode of processing the information contained in connected discourse.

Method

The method was exactly the same as Study 2 with the following exceptions:

1. There were 20 Ss instead of 8.

2. The eight passages were tape recorded by a professional announcer and S simply fixated upon the "5" on the number card while he listened to the passages as they were being played. Thus, the previous READ condition was replaced by a listening condition.

3. The passage order was always the same for each subject -- 1A, 2A, 3A, 4A, 1B, 2B, 3B, 4B.

4. There was only one control condition for each passage and that was the 20 sec. baseline condition, BFC. (The other two control conditions were necessary for reading only.)

5. There were 5 samples taken from each of the two conditions, BFC and listening. For each condition a measurement was taken at the instant that the eyelid opened to a position above the pupil, and at 5 sec. intervals thereafter to 20 sec. (i.e., 0, 5, 10, 15, and 20 sec. points). The 0 sec. point was measured to provide an indication of the precision of the measurement procedures.

6. The dependent variable analyzed was the pupil diameter during the listening sample minus the diameter during the corresponding control sample. For example, the pupil dilation at the 5 sec. point for the control condition was subtracted from the diameter at the 5 sec. point for the listening condition. This measure of dilation was calculated for each of the four sample points (5, 10, 15, 20) and the four passages (1B, 2B, 3B, and 4B).

Results and Discussion

Mean comprehension scores for the four passages were approximately equal to the means in Studies 1 and 2 (7.8, 6.8, 4.6, and 2.6).

Table 6 contains the mean pupil dilations in relation to the baseline control (BFC) for four sampling positions and the four passages. Notice that only two of the 24 t tests for dilation were statistically significant. These two statistically significant differences are probably chance occurrences since neither the marginal means for sampling points or levels of difficulty suggest a trend. All the marginals are close to zero and none are above the accuracy of measurement, 0.10. However, in order to be sure that the size of the mean dilations were not large in relation to their variances, an analysis of variance was conducted. An ABS (see Lindquist, 1956) design was applied with the A variable representing the four sample points and the B variable representing the four passages varying in difficulty level. Neither the _F_ representing the main effects of A and B, nor the _F_ representing their interaction approached statistical significance at the .05 level.

TABLE 6

Mean Pupil Dilation in Relation to Baseline
for Three Sampling Points and Four Listening Passages (N=20)

	Sample Points				
Passage	5 Sec.	10 Sec.	15 Sec.	20 Sec.	Mean
1B	.02	.07	.00	.03	.03
2B	.12*	.04	.01	.01	.04
3B	.04	.00	.00	.00	.01
4B	.04	-.04	.01	.06*	.02
Mean	.05	.02	.00	.02	

*_t_-test significant beyond the .05 level.

Thus it appears that there is no evidence which would suggest that the pupil dilates while processing the information contained in aurally presented connected discourse.

In order to demonstrate that the procedures, techniques, and equipment were probably sufficiently sensitive to dilation had it occurred, the mean pupil diameter has been plotted in Figure 2 (on the following page) as a function of the sampling point for both the experimental and control conditions. These values represent an averaging over all four of the listening passages. Notice that there was a large drop in pupil diameter from the 0 point to the other four sampling points. Figure 2 graphically depicts the potential amount of dilation and the precision of measurement procedures as well as the essential equality of pupil size in the control and listening conditions.

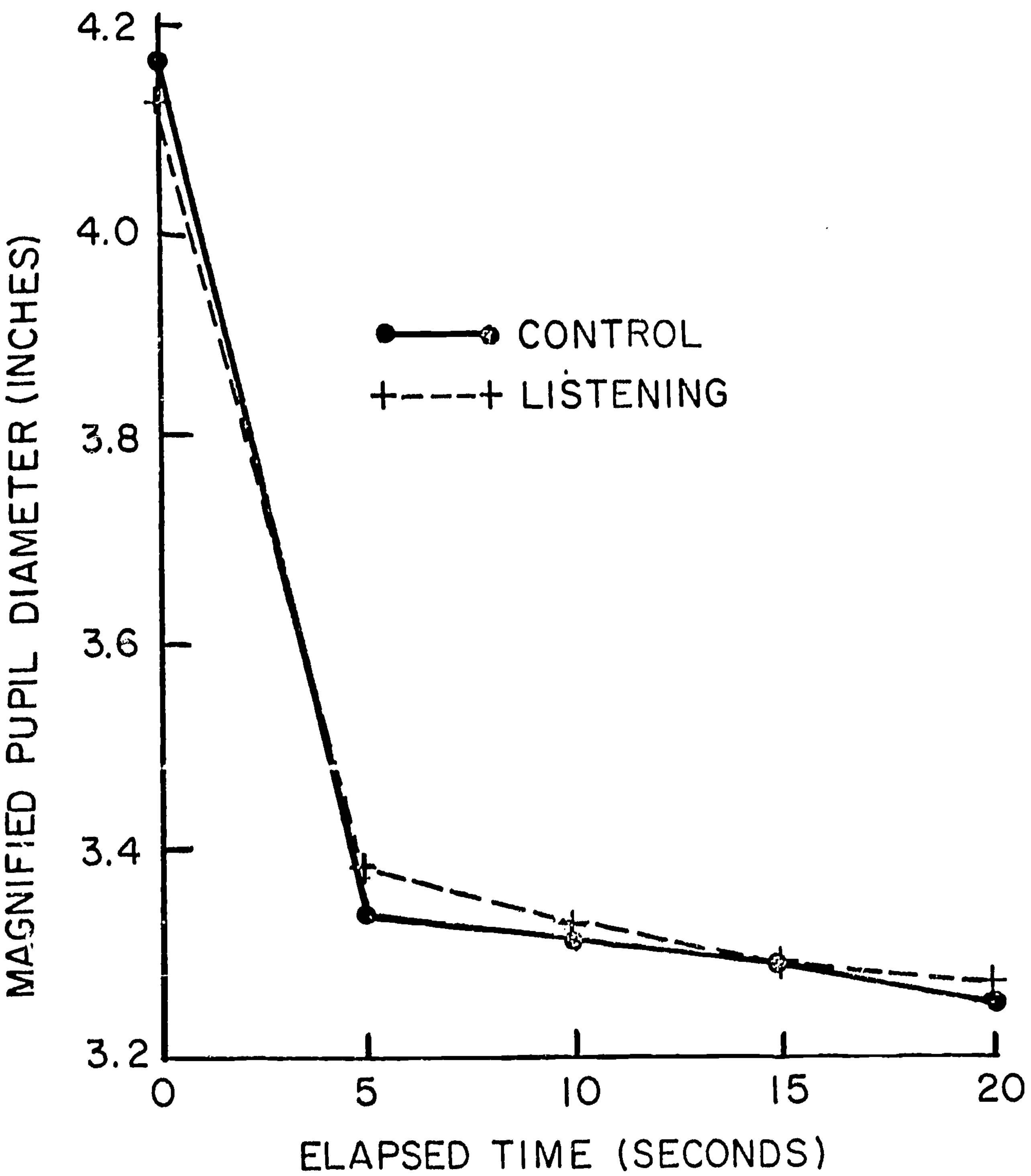

FIG. 2. MEAN PUPIL DIAMETER AS A FUNCTION OF THE TIME ELAPSED FROM THE OPENING OF THE EYE DURING A LISTENING CONDITION AND A NON-LISTENING CONTROL POSITION (N=20).

DISCUSSION AND CONCLUSIONS

The results of Studies 1, 2, 3, and 4, suggest that the pupil does not dilate while reading or listening to connected discourse. That is, it does not appear that pupil size can be used as an objective indication of whether or not an individual is, in fact, processing the information contained in connected discourse while supposedly engaged in reading or listening activities. What appeared, at the outset, to be a potential means of controlling and investigating the moment to moment changes in information processing and storage during reading and listening has not provided empirical data which substantiated this potential. Of course, the data collected may be an artifact of variables inadquately controlled in these studies. With these data, however, and without compelling contrary rationale, it does not appear fruitful to pursue pupil size as a possible indicator of the information processing and storage functions during reading or listening.

The data collected were not designed to provide definitive evidence with regard to the validity of pupil dilation as a measure of information processing load. However, these data are indirectly relevant to this concept. It appears certain that the subjects in the four studies were processing information during the experimental conditions. Furthermore, it seems reasonable to infer that the information processing load was greater under the reading and listening conditions as compared to the control conditions. Thus, an explanation for the failure to find dilation would seem to be in order.

Inadequate experimental method may be the explanation, yet this appears to be unlikely. Future research and critical evaluation by other investigators will permit a more adequate evaluation of this explanation.

Another explanation for these results could be that the processing load was minimal and the research techniqes were not precise enough to detect the corresponding small dilation. This explanation is highly plausible. It seems reasonable that the load during the processing of information during reading or listening may be small in relation to the load during the storage of a seven digit number (see Kahneman & Beatty, 1966). Since the conduct of the research reported here, the results of other pupil dilation experiments have become available (e.g., Kahneman & Peavler, 1969) which report pupil dilations of very low orders of magnitude. These data have been interpreted as providing evidence for the use of pupil dilation as an index of processing load. Yet, with 20 subjects and four observations per subject it would appear that reliable dilations would have been found had they existed in the listening study.

Finally, it may be that the concept of pupil dilation as a measure of information processing load is not fruitful. It is well known that the pupil dilates in response to emotional arousal and during the orienting response, and Kahneman and Beatty (1967) have discussed these effects as possible explanations for their own results. They admit that a choice between these competing interpretations is difficult since performance on more difficult tasks are generally accompanied by higher levels of anxiety.

The data from the four studies involving reading and listening can be interpreted as not providing supporting evidence for Kahneman's hypothesis that pupil dilation is an index of information processing load. Furthermore, data presented by Kahneman and Beatty (1966) as supporting the concept can alternately be interpreted as suggesting that pupil dilation is not an indicator of information processing load. That is, Kahneman and Beatty present curves of pupil dilation as a function of time during the presentation and recall of digit strings of varying length. The amount of dilation is shown to increase with the length of the digit strings, and the most pronounced effect is associated with the longest string, seven digits. These investigators acknowledged the effect of anxiety, an anticipatory effect, prior to a difficult trial, but stated that the initial dilation does not account for the main results. The inconsistency in their interpretation can be seen from a replot of their data so that dilation is plotted as a function of the number of digits presented. There is little doubt but that more dilation is associated with the longer digit strings when the load on memory (i.e., number of digits presented) is equal. Since the curves should all coincide as long as the number of digits presented are equal, these data are inconsistent with their interpretation. It appears that the anxiety associated with the anticipated longer strings is a more logical explanation for larger pupil sizes reported.

Peavler (1969) has recently collected data which he interpreted as providing evidence against the physiological or anxiety type of explanation and for the psychological or the processing load type of explanation. It appears that further research in pupil dilation will be required before the negative results in the four studies of this report can be explained with confidence. At this point it is difficult to be certain whether a small dilation occurred but was too small to measure, or whether it is theoretically unsound to expect a dilation, large or small.

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